1972
USDA FOREST SERVICE
RESEARCH PAPER PNW-141

Twenty-one-year DEVELOPMENT of Douglas-fir Stands Repeatedly Thinned at Varying Intervals

Donald L. Reukema

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE
PORTLAND, OREGON
U.S. DEPARTMENT OF AGRICULTURE

ABSTRACT

Douglas-fir stands first thinned at about age 38 have been observed for 21 years. Four treatments were compared: no thinning, light thinning at 3-year intervals, moderate thinning at 6-year intervals, and heavy thinning at 9-year intervals. Eighteen years after initial thinnings (the first common end to all thinning cycles), all thinned stands had virtually the same total cubic volume as before thinning and about 65 percent of what they would have had without thinning. Early thinnings tended to be from above; later thinnings from below.

Thinning interval had no effect on total growth per acre over the 21-year period, but gross growth in all thinned stands was about 20 percent less than that in comparable unthinned stands. There was only about half as much mortality in thinned as in unthinned stands, and enough was salvaged to largely offset the growth loss. Thinning had little effect on current relative tree-size distribution, because increased growth rate of residual trees was offset by removal of many larger-than-average trees. The primary benefit derived from these commercial thinnings was an earlier harvest of products, not a substantial increase in total usable production per acre.

Keywords: Thinning (trees), Douglas-fir, growth, yield.

CONTENTS

	Page
INTRODUCTION	1
METHODS	1
Design of Study	1
Measurements	2
Determination of Volume and Volume Growth	3
STUDY AREA	3
Location and Climate	3
Soils, Topography, and Site Index	3
The Stand	4
Distribution of Douglas-fir	4
Number and Size of Trees and Volume Per Acre	4
TREATMENT	4
Marking Guides	5
Severity of Thinning	5
Size and Crown Class of Cut and Dead Trees	7
STAND DEVELOPMENT	8
Mortality and Damage	8
Amount of Mortality	8
Causes of Mortality	10
Distribution of Mortality Over Time	10
Damage	10
Tree Size and Crown Class	10
D.b.h. and Height of Largest Trees	12
Cubic Volume Growth and Yield	14
Total 18-year Growth	14
Trends in Periodic Growth	15
Growth Percent	16
Redistribution of Increment	17
Yields	19
DISCUSSION AND MANAGEMENT IMPLICATIONS	20
SUMMARY AND CONCLUSIONS	21
LITERATURE CITED	22

INTRODUCTION

In 1947, the 220-acre Voight Creek Experimental Forest[1] was established in eastern Pierce County, Washington, to study the effects of commercial thinning on subsequent stand growth and development. Beginning at about age 38, commercial thinnings were made at intervals of 3, 6, and 9 years, designed to remove comparable volumes over an 18-year period. Results of the first 6 years of the study were reported by Worthington et al. in 1962.

This paper provides a comprehensive summary of stand development over a period of 21 years following the time of initial thinning. Many of the details presented pertain to the 18-year period following time of initial treatment. This is the earliest point in time at which a complete evaluation can be made, because the 18th year marks the first common end of thinning cycles in all treatments. This is supplemented by growth and mortality data for a seventh 3-year period (18th to 21st years after initial thinning) to update the noted trends.

Although commercial thinnings at Voight Creek have caused a substantial improvement in growth per unit of residual growing stock, they have also apparently caused a substantial reduction in gross growth per acre. This reduction in growth has been largely offset by salvage or forestalling of mortality, so that total usable yield to date is nearly the same in thinned and unthinned stands. Eighteen years after time of initial thinnings, the thinned stands (at about age 56) contained about 65 percent as much live volume as did the unthinned. Since future mortality in thinned stands should be less than in unthinned stands, growing stock should increase more rapidly in thinned than in unthinned stands. Thus, with no additional thinning we can expect total usable yield--from a final harvest at about age 80 plus thinnings--to be about 5 percent greater from thinned than from unthinned stands. Benefits from these commercial thinnings arise primarily from an earlier harvest of products, not from a substantial increase in the total volume of usable wood produced.

METHODS

DESIGN OF STUDY

The experiment was laid out in a randomized block design, with three replications of each of four treatments. Replications of treatments were staggered 1 year apart in time. Thus, the experimental forest is divided into three blocks and each block into four compartments (fig. 1). Within each block, treatments were assigned at random to the compartments. Compartments are approximately 17 acres in size; each is sampled by five tagged plots, which were systematically located without regard to stand or topographic conditions.[2]

The sample plots are multiple-radii circular plots on which larger trees are sampled more intensively than smaller trees. At the first measurement--just prior to initial treatment, trees 11.0 inches

[1] Maintained by the Pacific Northwest Forest and Range Experiment Station in cooperation with the St. Regis Paper Company.

[2] Each compartment was also sampled by 10 untagged plots, on which trees were not individually identified and diameters were recorded only to the nearest 2 inches. Analyses and results reported in this paper are based only on the more complete and reliable data obtained from tagged plots. Data collected on the untagged plots have been examined in less detail and support reported conclusions.

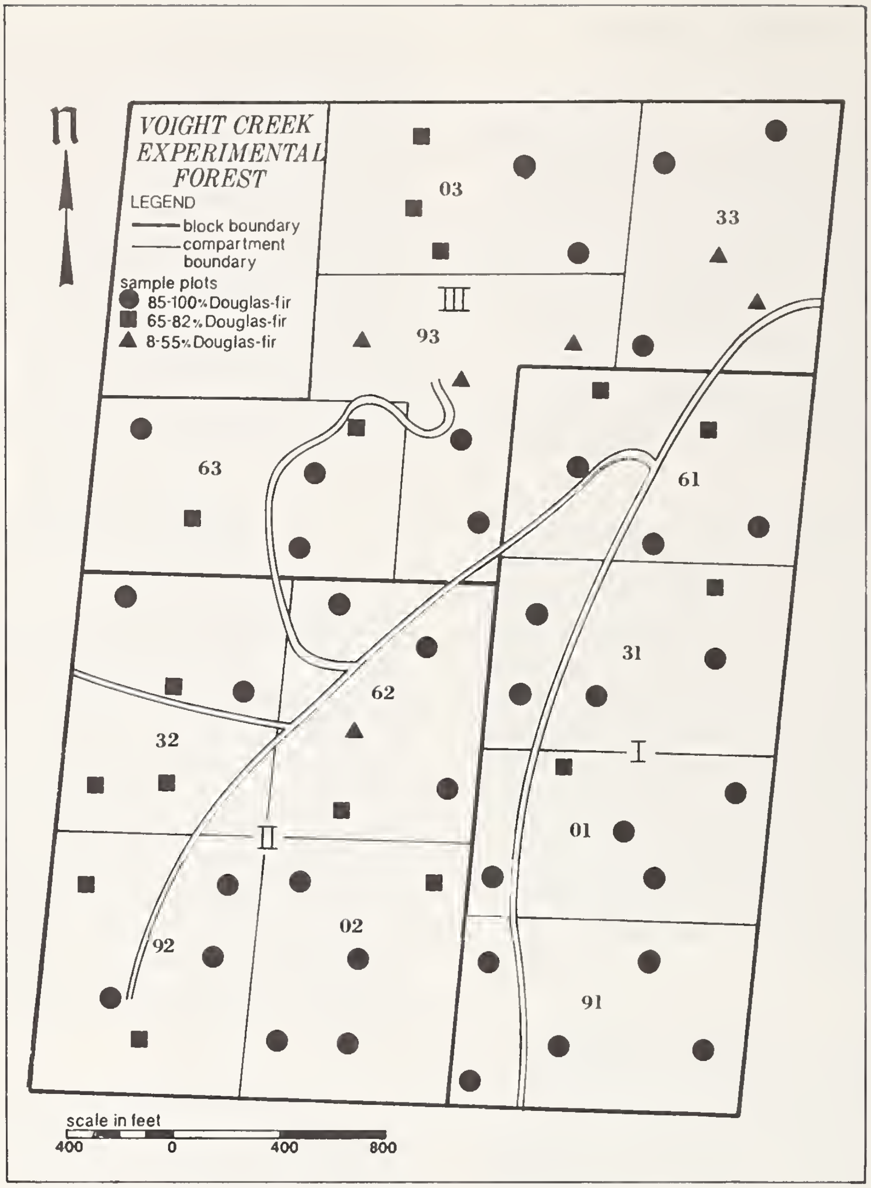

Figure 1.--*Layout of thinning units and sample plots.*

and larger were tagged on the entire 0.20-acre circular plot, trees 5.0 to 10.9 inches on a concentric 0.05-acre subplot, and trees 1.5 to 4.9 inches on the central 0.0125-acre subplot. It was found that this did not provide an adequate sample of 5- to 11-inch trees. Therefore, on all subsequent measurements, all trees 5.0 inches and larger were tagged on the entire 0.20-acre plot; trees smaller than 5.0 inches were still tagged on only the central 0.0125-acre subplot.

MEASUREMENTS

Measurements were taken at 3-year intervals, coincident with the shortest thinning cycle. At these times, d.b.h.'s of all tagged trees were measured to the

nearest 0.1 inch with a diameter tape. Type, severity, and cause of damage were noted, as were causes of mortality. Heights of six Douglas-fir trees per plot were measured, with four trees being larger and two trees smaller than the quadratic mean d.b.h.[3] The same trees were measured at successive measurements, except where substitution was necessary because of subsequent death, cut, or damage. Breast-height ages of dominant and codominant height trees were determined on increment cores.

DETERMINATION OF VOLUME AND VOLUME GROWTH

Volumes and volume growth during each period were determined for each plot independently. Cubic volumes of each of the six Douglas-fir trees measured for height at each 3-year measurement were calculated by an equation expressing cubic volume as a function of d.b.h. and height (Curtis 1966). Tarif numbers for each of these trees were calculated by the method of Turnbull and Hoyer (1965) and were then averaged to give a tarif number for the plot at each 3-year measurement. These averages were smoothed over time to avoid irregularities associated with measurement errors, substitution of trees, etc.

Volumes of each tree on the plot at each 3-year measurement were then calculated from its d.b.h. and the plot tarif number. This provided cubic volume of the total stem and merchantable volumes by several merchantability standards. These volumes were then multiplied by the necessary expansion factors and summed to give total volumes per acre.

[3] Quadratic mean d.b.h. is the d.b.h. of the tree of average basal area (Ford-Robertson 1971). Hereafter, mean d.b.h. refers to this quadratic mean.

Cubic volume growths of individual trees surviving each 3-year measurement period were summed to give gross growth per acre.

STUDY AREA

LOCATION AND CLIMATE

The experimental forest area is near Orting, Washington. It lies on a slope above the Carbon River, at an elevation of 830 to 1,140 feet. The nearest weather station (about 7 miles to the northeast at an elevation of 685 feet) shows an average precipitation of 49.3 inches, with 15.9 inches falling during the months of April through September, and an average annual temperature of 50.2° F., with an April-through-September average of 57.7° F.

Three damaging climatic disturbances occurred at Voight Creek during this study period. A cold wave in November 1955 (Duffield 1956, Reukema 1964a) caused freeze injury and drastically reduced subsequent growth on many trees. A severe windstorm in November 1958 and wet, heavy snow in November 1960 caused extensive breakage and uprooting. The 1962 Columbus Day windstorm, which caused extensive damage sporadically throughout the region, did virtually no immediate damage at Voight Creek. It may have set the stage for a small amount of uprooting the following spring. There have been no disturbances of any consequence since that time.

SOILS, TOPOGRAPHY, AND SITE INDEX

Soils are derived from material deposited by a Piedmont glacier from the Cascade Range. Two major soils exist. One (Barneston) is a gravelly sand overlying gravelly sandy loam; the other (Indianola) is a fine sandy loam or sandy clay loam. Topography is quite variable; gentle slopes, kettle depressions, abrupt

slopes along drainages, and some areas of fairly level land all occur on the experimental tract.

Site index averages about 145 and ranges from 100 to 170 (100-year index). Tarrant (1950) observed that site index did not differ significantly between soil types; but it did differ significantly between convex and concave topography on both soils, averaging about 15 percent greater on the concave topography.

THE STAND

Logged originally about 1900, the experimental forest area supports a stand that is fairly typical of young-growth Douglas-fir forests that have followed logging of virgin timber. The stand became established about 1912. Although quite uniform, it showed typical variation in degree of stocking, stand density, and species composition. Since sample plots were located without regard to stand conditions, they sample this entire range of variation.

Distribution of Douglas-fir

Many plots are not fully occupied by Douglas-fir trees. A few contain large openings in the stand. Others contain other species.

The degree of incomplete stocking (occupancy) due to openings is difficult to quantify, because we do not know how much of the apparent opening is, in fact, being utilized by surrounding trees. A subjective evaluation suggests that occupancy of the plot area, by all species, varied from about 50 to 100 percent. Some of these openings have apparently existed from the time of stand establishment, whereas others are of more recent origin, due to root rot, storm damage, or both.

Species composition has been expressed as volume of each species as a percent of the plot total. On the 54 plots considered here, Douglas-fir volume was 65 to 100 percent of the total, averaging 90 percent.[4] On some plots, other species were mostly conifers--principally hemlock and/or western redcedar; on others, they were mostly hardwoods--principally alder, cottonwood, and/or maple. On some, other species were concentrated on a portion of the plot; on others, they were intermixed with Douglas-fir, often occupying an understory position.

Number and Size of Trees and Volume Per Acre

Due to initial variations in site-quality, stocking, and density, there was considerable variation in number and size of trees on these plots. On the average, the pretreatment stand at age 38 contained about 745 stems per acre, with a mean d. b. h. of 6. 7 inches (table 1). About 320 of these trees, with a mean d. b. h. of 9. 3 inches, were of merchantable size (d. b. h. of 5. 6 inches or larger). The 100 largest trees per acre had a mean d. b. h. of 11. 7 inches.

Total cubic volume per acre was estimated to average about 5, 800 cubic feet (table 1). About 14 percent of this volume was in trees which were not of merchantable size. Pretreatment volumes were closely correlated with site index, with the linear relationship accounting for 87 percent of the variation in compartment average volume.

TREATMENT

Except for thinning interval, there was very loose control over treatment

[4] Six plots on which Douglas-fir volume was 8 to 55 percent of the total have been excluded from further consideration in this paper.

Table 1.--*Descriptive characteristics of stands before thinning (age 38)*[1]

Compartment[2]	Site index	Trees per acre	Average d.b.h.	Cubic volume per acre	D.b.h. of 100 largest Douglas-fir
		Number	*Inches*	*Cubic feet*	*Inches*
01	120	1,090	5.1	4,088	9.1
02	132	618	6.5	4,767	11.5
03	156	695	6.8	6,263	11.5
31	148	867	6.3	5,723	10.6
32	160	775	7.1	6,873	14.4
33	158	540	8.7	6,930	12.3
61	144	855	6.0	5,186	10.5
62	146	455	8.2	6,198	11.8
63	154	663	7.5	7,065	13.1
91	144	752	6.5	5,305	11.8
92	144	619	7.0	5,719	13.0
93	160	1,025	6.5	7,515	12.0
Weighted average	147	744	6.7	5,844	11.8

[1] All species, trees 1.5 inches and larger in d.b.h.

[2] First digit of compartment number denotes thinning interval and second digit denotes replication. Each compartment average is based on 5 plots, except for 3, 4, and 2 plots, respectively, on compartments 33, 62, and 93.

actually applied to plots. Thus, in reality, rather than four treatments, there was a wide range in treatments applied to plots, involving variations in thinning intensity and type of thinning, as well as thinning interval.

MARKING GUIDES

Marking for thinning followed the priority system described in the commercial thinning bulletin (Worthington and Staebler 1961). First priority was given to removing merchantable dead or dying trees and trees marking negligible growth compared with the average. Second priority was given to removing "wolf trees," provided surrounding trees were judged capable of response. Third priority was given to improving spacing of remaining trees.

Priority I removed many intermediate and suppressed trees, but also some dominants and codominants; many suppressed trees were too small to cut. Such trees were removed in about equal number at all thinnings. Many priority II trees were cut at the initial thinnings (including first two thinnings on the 3-year cycle). Priority III trees were cut at all thinnings, their proportion increasing at successive thinnings.

SEVERITY OF THINNING

Initial thinnings, averaged by treatment, removed 12, 22, and 31 percent of the pretreatment volume on the 3-, 6-, and 9-year cycles, respectively (fig. 2). Compartment averages ranged from 10 to 34 percent. Subsequent thinnings plus mortality[5] removed an average of 90

[5] For practical purposes, mortality must be considered as both (1) a variable affected by treatment and (2) part of the treatment. Loss of trees due to natural causes should have a similar impact on surrounding trees as would loss of those same trees through cutting them.

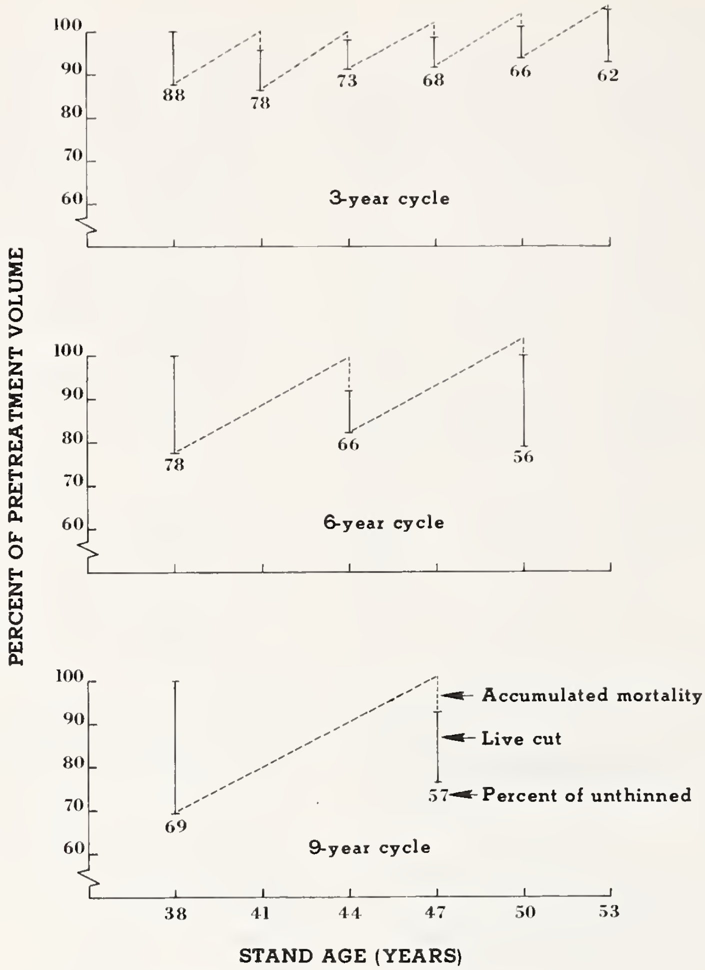

Figure 2.--*Severity of thinnings.*

percent of the gross increment accrued since the previous thinning, thus allowing residual growing stock to increase by only 10 percent. Some thinnings removed considerably more of the increment than this. In contrast, most thinning guides for Douglas-fir would let the volume increase more rapidly (e.g., Bradley et al. 1966, Harmon 1969, Staebler 1960).

Eighteen years after initial thinnings, standing cubic volume in thinned stands was nearly equal to the pretreatment volume, and about 64 percent of what it would have been if the stands had not been thinned (fig. 3). The stands, of course, arrived at this common value through quite different routes. Both the third thinning on the 6-year cycle and the second thinning on the 9-year cycle reduced volume to less than 60 percent of normal (fig. 2).

As seen, thinnings removed much more than normal mortality. Over the 18-year period, mortality in unthinned stands removed 23 percent of all stems which reached 5.6 inches or larger and an average of 25 percent of the pretreatment volume. Thinnings plus mortality in thinned stands removed an average of

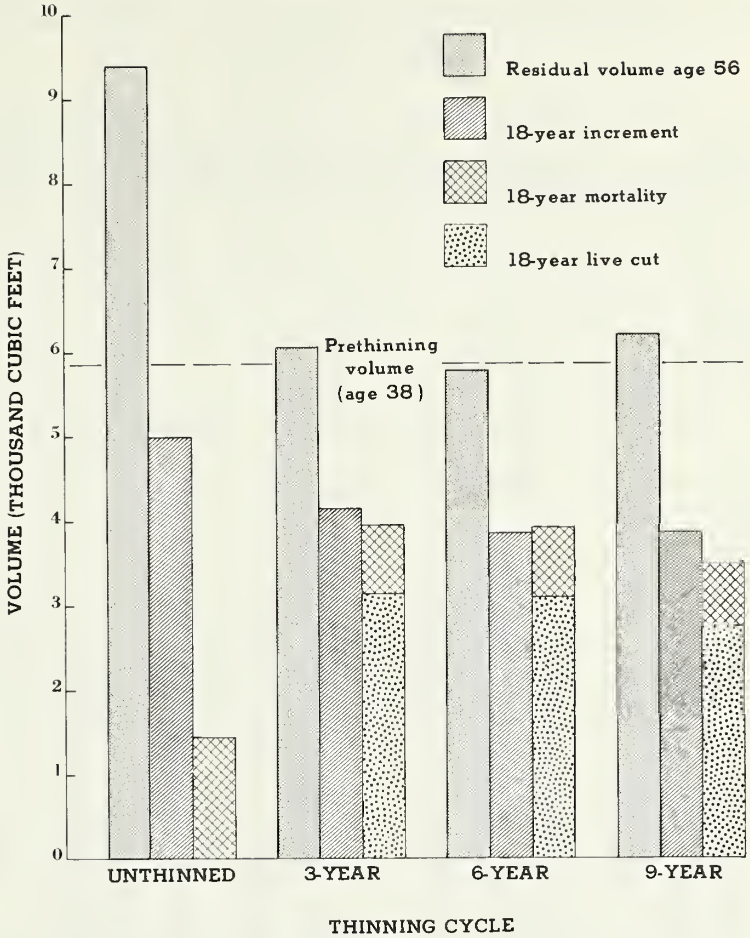

Figure 3.--*Eighteen-year growth and yield, by treatment (adjusted to average pretreatment volume).*

54 percent of all stems which reached a d. b. h. of 5. 6 inches or larger, and a volume equal to an average of 65 percent of the pretreatment volume.

SIZE AND CROWN CLASS OF CUT AND DEAD TREES

The average d. b. h. of trees cut in all thinnings was 10. 5 inches. Size of cut trees was generally greater at initial thinnings (and second thinnings on the 3-year cycle) than at subsequent thinnings. The ratio of d. b. h. of cut trees to average d. b. h. before thinning (d/D) was greater than 1. 0 at the initial thinning on all compartments; the d/D ratio then tended to be less than 1. 0 at subsequent thinnings.

Thinnings removed a different stand component than did natural mortality. Only 13 percent of the dead trees were in the dominant and codominant crown classes, and 49 percent were suppressed. On the other hand, an average of 52 percent of the cut trees were in the dominant and codominant crown classes, and only 9 percent of them were suppressed (table 2).

Table 2.--*Distribution of cut and dead trees among crown classes over an 18-year period*[1]

Treatment	Crown class			
	Dominant	Codominant	Intermediate	Suppressed
	Percent of total cut			
3-year cycle	11	32	47	8
6-year cycle	16	34	37	11
9-year cycle	27	36	28	7
	Percent of total dead			
Unthinned	5	12	34	48
3-year cycle	7	7	30	55
6-year cycle	4	8	32	54
9-year cycle	2	8	50	38

[1] All species, trees 1.5 inches and larger in d.b.h.

The percent of cut volume removed from the codominant crown class was about the same in all thinning treatments, whereas the number of dominants cut was greater, and the number of intermediates cut was less, with the longer thinning cycle.

An average of 44 trees were cut from among the original 100 largest Douglas-fir per acre, the greatest number being associated with the 9-year thinning cycle (table 3). The preponderance of such cut trees was at the initial thinnings, where the number cut was nearly proportional to the percent of volume cut. Some were cut at all thinnings, partly to improve spacing and partly to remove trees which were apparently unhealthy. In contrast, only three of the 100 largest per acre died in the unthinned stands.

STAND DEVELOPMENT

MORTALITY AND DAMAGE

Amount of Mortality

Generally there was less mortality in thinned than in unthinned stands, although differences are not statistically significant.[6] On the average, mortality during the 18 years removed about 300 trees per acre, having a volume of about 950 cubic feet (fig. 4). Expressed as a percent of initial volume, an average of 25 percent was lost in unthinned stands compared with an average of 14 percent in thinned stands. Volume lost to mortality in unthinned stands equalled 30 percent

[6] Wherever the term "significant" is used in this paper, it refers to statistical significance at the 5-percent level.

Table 3.--*Number of trees cut or dead from among the original 100 largest Douglas-fir per acre*

Treatment	Period						
	1	2	3	4	5	6	Total
Unthinned	0	1	0	0	2	0	3
3-year cycle	13	8	5	3	3	6	38
6-year cycle	25	0	7	1	10	0	43
9-year cycle	42	0	0	9	1	0	52
Thinned plot average	--	--	--	--	--	--	44

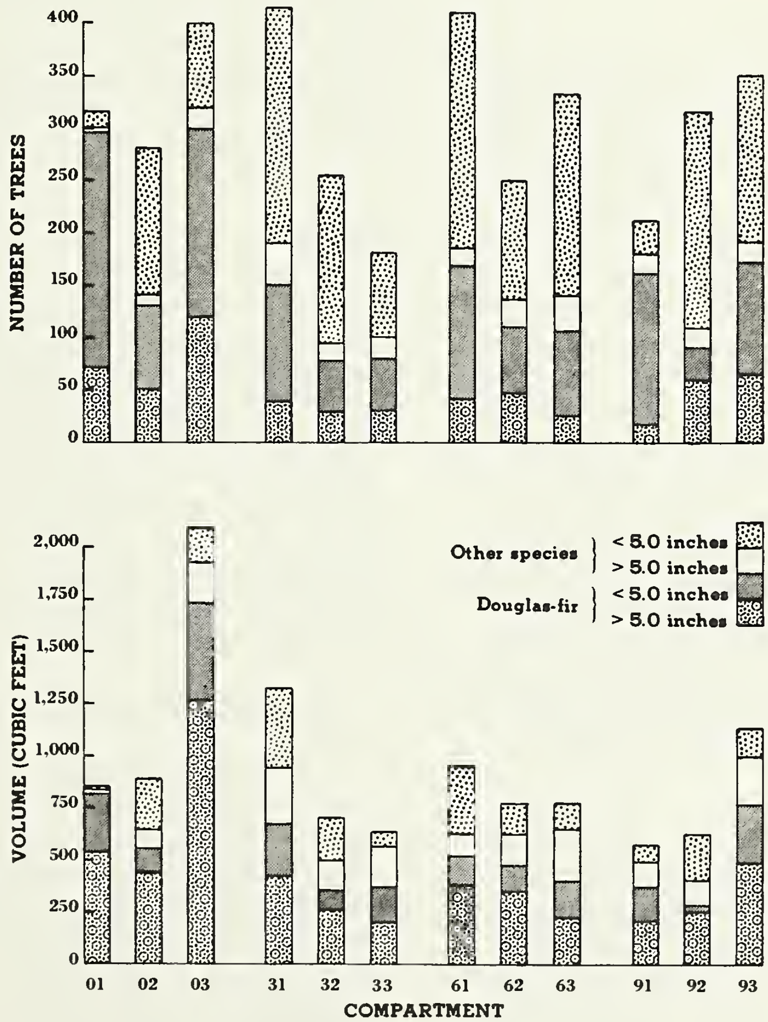

Figure 4.--*Distribution of mortality, by species and size classes.*

of the 18-year gross growth, therefore following normal trends.

Distribution of mortality by species and size class varied with stand structure. However, differences in amount of mortality were not closely related to this variation. Thirty-eight percent of the cubic volume lost was in trees smaller than 5-inch d.b.h. and 10 percent was in trees larger than 11-inch d.b.h. Additional information on size and crown class distribution of dead trees has already been presented in the discussion of treatment (tables 2 and 3).

Causes of Mortality

Mortality has been categorized by seven "causes"--suppression, unhealthy, uprooted, broken, logging, snow and freeze, and unknown. For purposes of comparison, losses due to each cause have been expressed as a percent of total volume lost in unthinned stands and in thinned stands (table 4). Since total mortality averaged less in thinned stands, a given percent corresponds to less cubic volume in thinned stands than in unthinned stands. The "unhealthy" category includes all dead standing trees which died of root rot or which had been observed to be unhealthy at the previous measurement. It does not include trees which were windthrown because of root rot; all uprooted trees, regardless of cause, were classified as "uprooted." "Unknown" includes both trees which we could not classify and those which we inadvertently failed to classify.

Relative losses due to root rot and storm damage were similar in thinned and unthinned stands. Suppression mortality was twice as great in unthinned stands as in thinned stands and accounted for about half of the Douglas-fir volume lost in unthinned stands. Logging damage was, of course, confined to thinned stands and accounted for 15 percent of the Douglas-fir volume loss. Losses due to this cause tended to be greater on the 9-year thinning cycle and less on the 3-year cycle; most were a result of the initial thinning.

Distribution of Mortality Over Time

Distribution of mortality over time was very erratic. Mortality tended to be greater in thinned stands during the first period and greater in unthinned stands during the more recent periods (table 5). Most of the breakage and much of the uprooting were associated with the snow and windstorms mentioned earlier. However, broken trees, as well as those suffering other types of damage, often did not die during the period in which they were damaged.

Damage

Growth rate was not clearly related to type or severity of damage, as we have defined them. Many of the trees which survived the 18-year period have suffered damage, including several of the 100 largest Douglas-fir per acre. Some of this damage quite obviously reduced the growth of the damaged trees, whereas other damage had no apparent effect on growth. Also, many trees on which we have noted no damage have shown unexplainable rapid decline in growth rate.

TREE SIZE AND CROWN CLASS

Thinning only slightly changed the relative tree size distribution in favor of larger trees (fig. 5). Since there is no way of reasonably adjusting for pretreatment differences in size distribution, the most valid comparison possible is between the average of thinned compartments and the most comparable (best) unthinned compartment. The number of residual

Table 4.--*Distribution of dead volume by cause*[1]

Cause	Unthinned	Thinned
	------------*Percent of total*------------	
	DOUGLAS-FIR	
Suppression	48	26
Unhealthy	12	13
Uprooted	13	18
Broken	11	9
Logging	0	15
Snow, freeze	1	0
Unknown	15	18
	ALL SPECIES	
Suppression	45	22
Unhealthy	10	7
Uprooted	15	15
Broken	11	8
Logging	0	20
Snow, freeze	0	2
Unknown	18	28

1/ Trees 1.5 inches and larger in d.b.h.

Table 5.--*Distribution of mortality over time*[1]

Treatment	Period							21-year total
	1	2	3	4	5	6	7	
	-------------*Percent of pretreatment cubic volume*-------------							
Unthinned	3.5	2.3	3.7	6.6	4.9	3.6	3.4	28.0
3-year cycle	4.0	1.8	3.2	3.0	1.2	.6	.6	14.4
6-year cycle	5.5	2.1	1.9	1.9	1.6	1.0	.5	14.4
9-year cycle	5.9	1.3	1.1	1.4	1.7	1.4	1.3	14.1

1/ All species, trees 1.5 inches and larger in d.b.h.

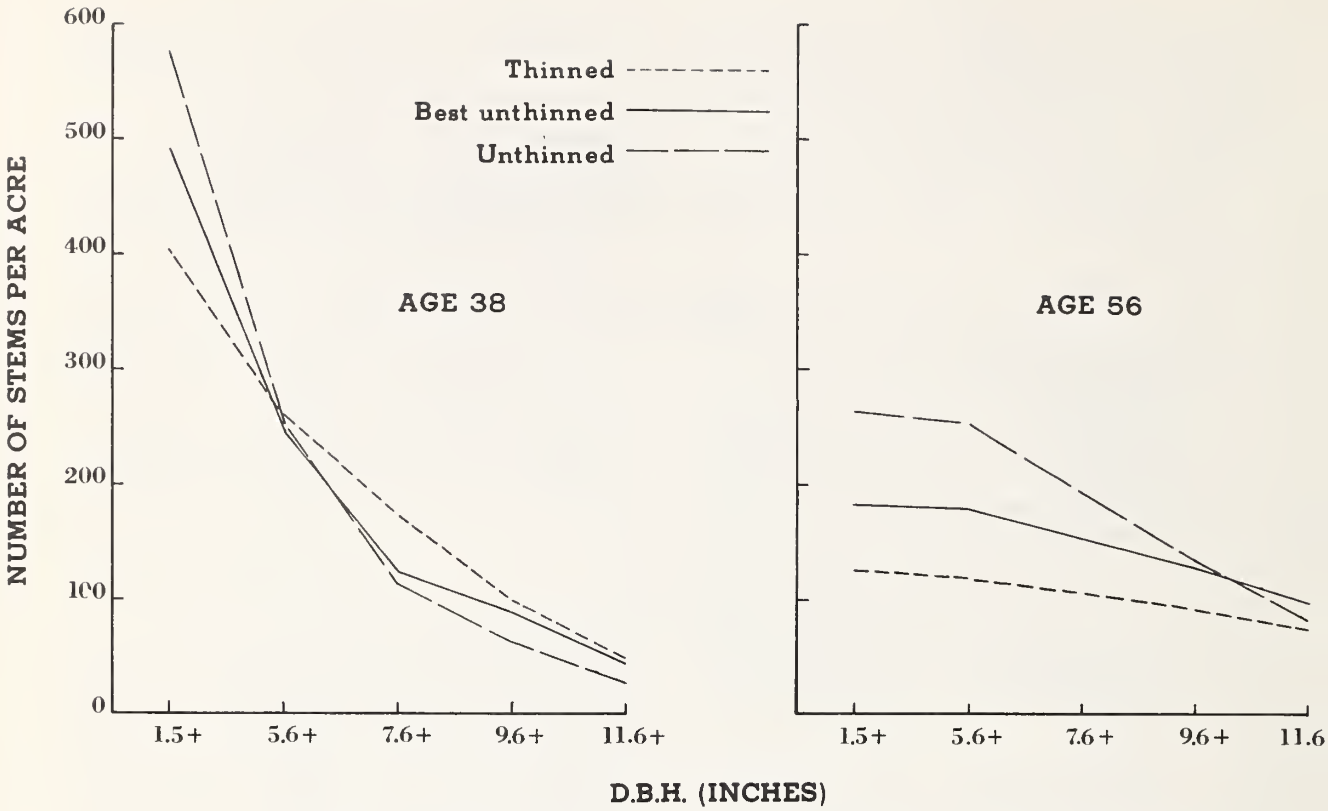

Figure 5.--*Stems per acre larger than specified minimum d.b.h. Douglas-fir component only.*

sawtimber-size trees is less in thinned than unthinned stands, and the thinned stands still contain a substantial number of smaller merchantable trees. Likewise, thinned stands generally have fewer residual dominant and codominant trees than unthinned stands but still contain substantial numbers of intermediate trees which are of merchantable size. As regards tree size distribution, the benefit of increased rate of diameter growth on remaining trees was largely offset by removal of many larger-than-average trees in thinnings.

D.b.h. and Height of Largest Trees

Average d.b.h. of the 100 largest trees per acre is frequently used as a measure of "crop tree" development. In the case of Voight Creek, this average is rather meaningless since an average of 44 percent of the original 100 largest Douglas-firs on thinned plots was removed in thinnings (table 3). If we choose the largest 40 Douglas-fir trees per acre (eight per plot) as our measure of crop tree development, thus using a common European standard, the impact of cutting the larger trees is reduced, although not overcome. In the 18th year, d.b.h. of these trees averaged 17.4 inches; periodic annual increment during the preceding 15 years averaged 0.28 inch (table 6). Growth on these largest trees was slightly, but not significantly, greater in thinned stands than in unthinned stands.

Table 6.--*D.b.h. and height growth of the largest Douglas-fir trees, between ages 41 and 56*

Compartment [1]	D.b.h. of 40 largest trees [2]		Height of five tallest trees [4]	
	Ending d.b.h.	15-year p.a.i. [3]	Ending height	15-year p.a.i. [3]
	--------------*Inches*--------------		--------------*Feet*--------------	
01	14.0	0.19	103	1.27
02	17.0	.21	118	1.73
03	19.0	.30	132	1.87
31	16.6	.29	117	1.40
32	20.5	.31	127	1.27
33	18.0	.28	127	1.80
61	16.0	.29	118	1.73
62	17.2	.27	123	1.73
63	19.4	.31	131	1.73
91	15.8	.23	114	1.20
92	17.8	.31	123	1.53
93	16.9	.33	123	1.27
Average	17.4	.28	122	1.57

[1] First digit of compartment number denotes thinning interval and second digit denotes replication. Each compartment average is based on 5 plots, except for 3, 4, and 2 plots, respectively, on compartments 33, 62, and 93.
[2] D.b.h. of the 8 largest Douglas-fir trees per plot (40 per acre).
[3] Periodic annual increment.
[4] Average height of the tallest measured Douglas-fir trees per plot (5 per acre).

A reasonable estimate of dominant height and height growth may be obtained by considering only the one tallest measured tree per plot (five per acre).[7] At age 56 (18 years after the initial thinnings) heights of these tallest trees averaged 122 feet. During the preceding 15 years, height growth of these trees averaged about 1.6 feet per year (table 6). Variations around this average were not closely related to either initial height or treatment, although it appears that thinning may have reduced height growth in some instances. This is in line with earlier observations of reduced height growth on released codominant trees (Reukema 1964b).

[7] There was often a wide variation in heights of dominant trees on any one plot; at age 56, the range in heights of measured dominant Douglas-fir trees exceeded 20 feet on 10 plots.

CUBIC VOLUME GROWTH AND YIELD

Total 18-year Growth

The measured 18-year gross growth, averaged by compartments, ranged from about 3,350 to 5,200 cubic feet per acre (186 to 289 cubic feet per year) and bore no significant relationship to treatment (table 7). However, when we adjust for pretreatment differences, then it is apparent that thinning reduced gross growth by an average of about 20 percent (fig. 6).

In unthinned stands, 18-year growth averaged 84 percent of pretreatment volume, and growth in all three compartments was very close to this average. Growth in the thinned compartments averaged only 67 percent of the pretreatment volume; it varied widely around this average but was always less than in unthinned stands. Greater variation is to be expected in thinned stands, since there was such wide variation in treatment.

Table 7.--*Cubic volume growth and yield*[1]

Compartment[2]	Pretreatment volume	Ending volume	Percent change	18-year gross increment	
				Volume	Percent of pretreatment
	--------*Cubic feet*--------			-*Cubic feet*-	
01	4,088	6,813	66	3,597	88
02	4,767	7,900	66	4,027	84
03	6,263	9,305	49	5,162	82
31	5,723	5,802	1	4,053	71
32	6,873	7,148	4	5,184	75
33	6,930	7,057	2	4,528	65
61	5,186	5,773	11	3,952	76
62	6,198	5,406	-13	3,571	58
63	7,065	6,864	-3	4,534	64
91	5,305	5,431	2	3,341	63
92	5,717	6,393	12	4,160	72
93	7,515	7,464	-1	4,669	62

[1] All species, trees 1.5 inches and larger d.b.h.

[2] First digit of compartment number denotes thinning interval and second digit denotes replication. Each compartment average is based on 5 plots, except for 3, 4, and 2 plots, respectively, on compartments 33, 62, and 93.

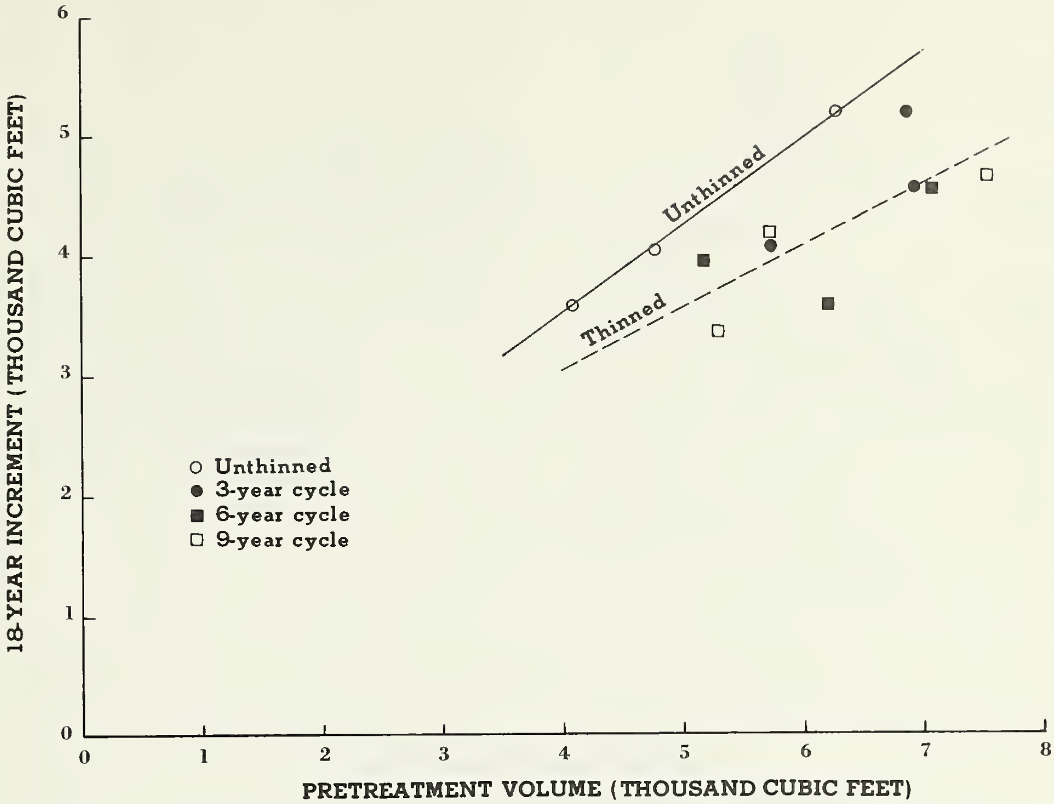

Figure 6.--*Relationship between increment and pretreatment volume.*

Trends in Periodic Growth

Fluctuations in 3-year periodic growth are associated with both treatment and climate. The most obvious influence of climate in this instance was the reduction in growth rate associated with the 1955 freeze. Other variations, most likely associated with precipitation and temperature, are apparent in the periodic growth rates of unthinned stands. Effects of treatment cannot be readily seen until we first remove the effects of this climatic variation. This has been accomplished by expressing growth in thinned stands as a percent of that in corresponding unthinned stands (fig. 7).[8]

[8] With growth expressed as a percent of pretreatment volume to adjust for initial differences.

In all periods, gross growth in thinned stands has been less than that in unthinned stands. The greatest reductions in growth rate occurred in the period immediately following initial thinnings, at which time the reduction in growth relative to unthinned stands tended to be about equal to the percent of volume which was cut. Growth in the second period following each thinning generally exceeded that in the first, indicating a partial redistribution of growth after a short delay.

Growth reduction associated with the 1955 freeze (i.e., in the third period) was greater in thinned than in unthinned stands. Reductions in growth following thinning in this period were greater than average for such light thinnings. However, rate of recovery was also greater in thinned stands.

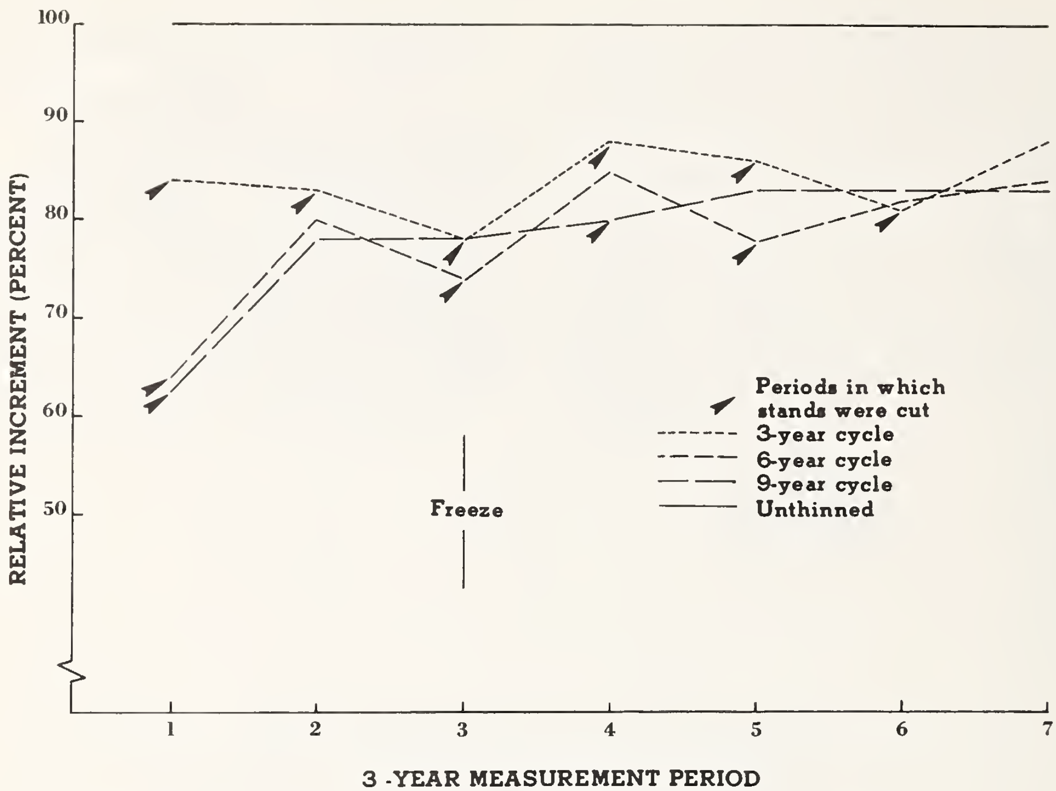

Figure 7.--*Growth in thinned stands relative to unthinned, adjusted by pretreatment volume (average of three blocks).*

Indications are that, without further thinning, growth per acre in thinned stands will slowly approach that in unthinned stands. However, during the most recent period (18 to 21 years after initial thinning), growth in thinned stands still averaged 15 percent less than that in unthinned stands.

Growth Percent

Growth percent provides a measure of efficiency of residual growing stock--growth per unit of growing stock.[9] Treatment did not have a significant effect on growth percent during the first period; it tended to reduce growth in proportion to the amount of growing stock removed. Thereafter, growth percent was consistently greater in thinned than in unthinned stands (fig. 8). Increases in relative growth percent immediately following subsequent thinnings generally were closely related to severity of cut; the more severe the cut, the greater the increase in relative growth percent.

Growth percent in thinned stands relative to unthinned stands has increased fairly steadily over time. During the most recent period (18th-21st years), the average growth percent in thinned stands was about 25 percent greater than that in unthinned stands. With no further thinning, the difference should tend to remain nearly constant.

[9] Growth percent is defined as 3-year periodic annual growth divided by average volume present during that 3-year period.

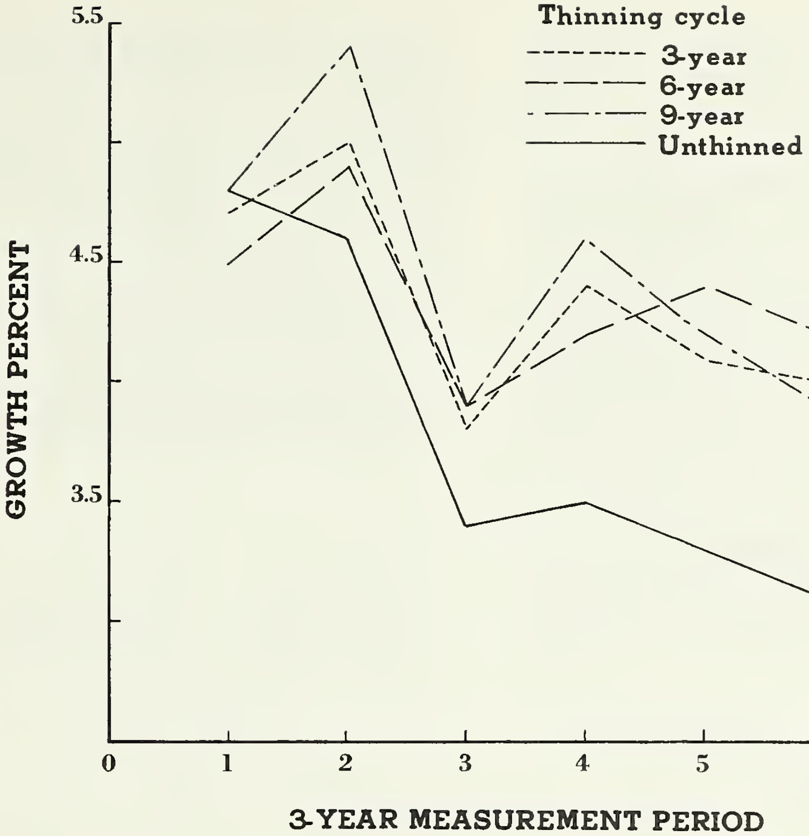

Figure 8.--*Periodic annual growth percent, by treatment and period.*

Redistribution of Increment

The increase in growth percent achieved by thinning is due to a combination of two factors: (1) growth of individual residual trees is improved and (2) less efficient trees are removed. The first involves a true redistribution of the growth capacity of the site; the second does not. If the less efficient trees were cut, the growth percent of the stand would be increased even if there were no redistribution of increment. Likewise, if the more efficient trees were cut, growth percent could be reduced even if there were some redistribution of increment. This presumably accounts for reduced growth percent in some instances following the initial thinnings.

Examination of periodic growth of surviving trees shows that there was, in fact, a substantial improvement in their growth rate relative to that during the first period of observation (fig. 9).[10] In

[10] Unfortunately, this first period of observation was the period beginning 3 years after initial treatment; we had no measure of growth prior to treatment and could not use the first period after treatment because many trees were not included in the smaller sample.

figure 9, growth during each 3-year period is expressed as a percent of the average pretreatment (age 38) volume for each treatment. The dotted lines show the trends of total growth per acre in successive periods. The bottom solid line represents the growth trend of trees which survived the entire 18-year thinning period, and the other solid lines represent trees which survived for shorter periods of time. The total growth per acre was, of course, distributed over progressively fewer trees in each successive period. Thus, the trees which accounted for 100 percent of the growth per acre at one point in time (e.g., 18 years after initial thinnings) had accounted for only a portion of the growth at an earlier point in time. The differences between the dotted line and the solid line in the period prior to their convergence indicates the portion of total growth which was added to trees which were then cut during the subsequent period, and which growth we hoped to redistribute.

Note that whereas growth in all treatments was much less in the third period

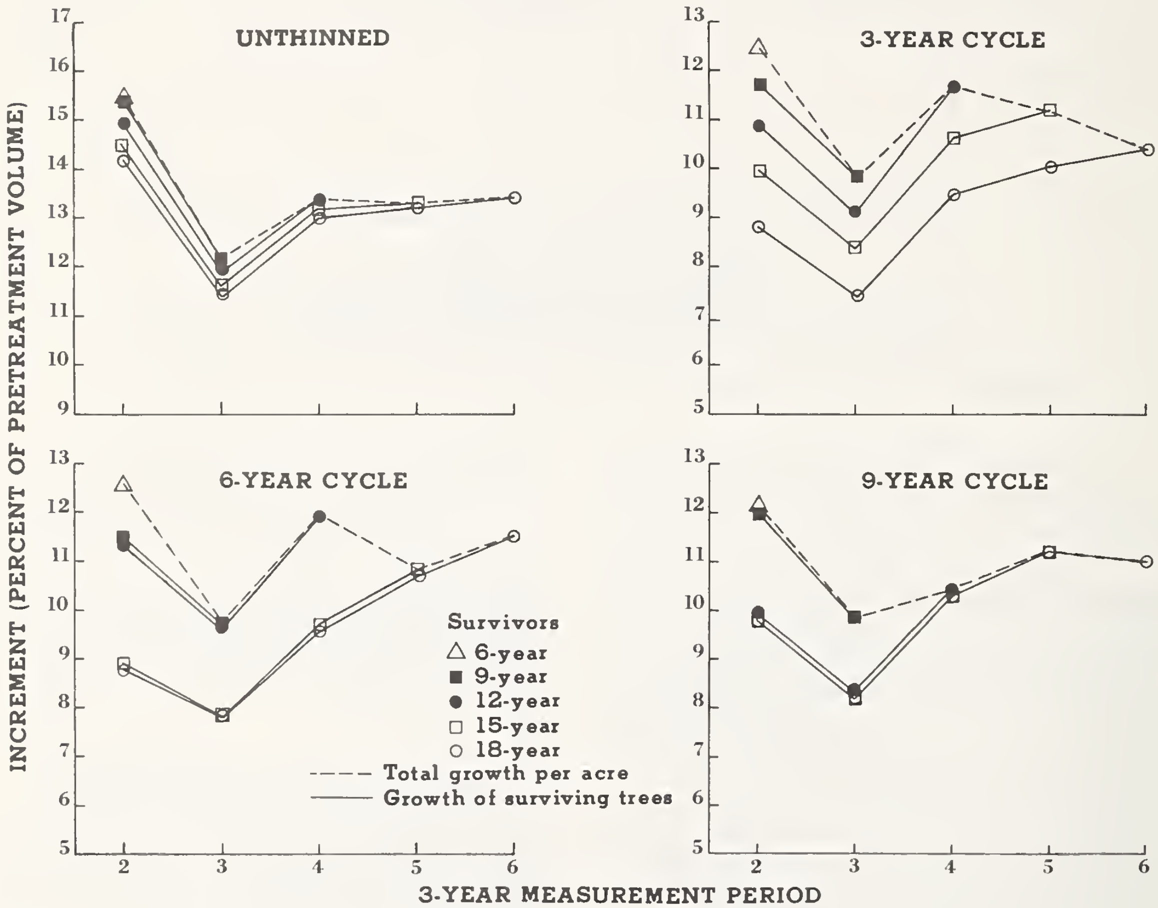

Figure 9.--*Growth of surviving trees relative to total growth per acre, Douglas-fir (with growth expressed as a percent of pretreatment volume at age 38).*

than in the second (primarily because of the 1955 freeze), relative growth in subsequent periods varied substantially with treatment. For example, in the unthinned stands, growth of each component was less in the fourth period than in the second, whereas in thinned stands it was consistently greater in the fourth period than in the second. Likewise, growth of each component in thinned stands further increased substantially in the fifth period, whereas that in unthinned stands remained nearly constant. This reflects the stimulatory effect of thinning on growth of surviving trees.

Yields

At age 59, 21 years after the initial thinnings, thinned stands contained about two-thirds as much residual volume as did unthinned stands: 6,625 vs. 10,000 cubic feet, when adjusted to the average pretreatment volume (fig. 10). In addition to this standing volume of 6,625 cubic feet in thinned stands, thinnings (including salvable mortality) captured about 3,555 cubic feet. Thus, if we were to make the final harvest today, total usable volume obtained from thinned stands (final harvest plus thinnings) would be 1.8 percent greater than that from unthinned stands.

We can use normal yield tables (McArdle et al. 1961, Staebler 1955) and past trends from this study to predict production to age 80--the anticipated time of final harvest. The resulting net yield in unthinned stands at age 80 will be 13,200 cubic feet. If we assume that gross growth

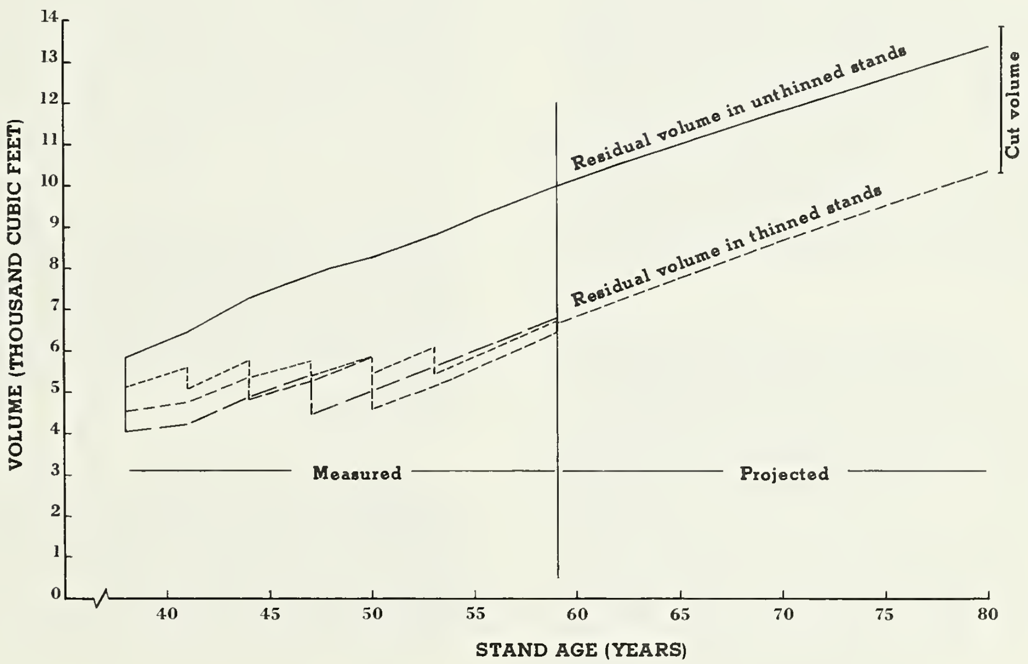

Figure 10.--*Projected effect of thinning on yield to age 80 (adjusted to average pretreatment volume).*

in thinned stands will average 90 percent of normal (and the control) and that mortality will be 50 percent of normal, then the volume present at age 80 will be 10,120 cubic feet. This volume plus the 3,555 cubic feet removed in thinnings gives a total usable production of 13,675--3.6 percent more than that from unthinned stands. If, instead, growth averages 95 percent of normal and mortality 35 percent of normal, then residual volume at age 80 will be 10,595 cubic feet. Total usable yield will be 14,150 cubic feet--7.2 percent more than from unthinned stands. Actual yield should be within this range, probably closer to the lower value.

DISCUSSION AND MANAGEMENT IMPLICATIONS

The commercial thinning bulletin (Worthington and Staebler 1961) states that two major objectives of commercial thinning, if realized, will result in economic gain: (1) redistribution of growth potential of the stand to optimum advantage, involving tree size and quality considerations; and (2) utilization of all merchantable material produced by a stand during a rotation.

A substantial amount of mortality was associated with initial thinnings. Thereafter, the amount of mortality occurring in thinned stands was clearly less than that in unthinned stands. Subsequent thinnings salvaged much, but not all, of the merchantable mortality which did occur. A little more was lost on the longer thinning cycles than on the short cycles.

Gains from redistribution of growth depend upon whether remaining trees will speed their growth rate *sufficiently* to make up for the loss in growth of trees removed. In the case of Voight Creek, we did not succeed in fully redistributing growth over a 21-year period. Variation in the amount of reduction was not influenced by thinning interval per se. Variation from one period to another and that among compartments thinned on the same cycle was influenced by severity and type of thinning, but the effect of each variable alone could not be determined. Undoubtedly, if thinnings could have been begun earlier, growth capacity of the site would have been more efficiently redistributed. Possibly if fewer of the largest trees had been cut, growth would have been redistributed more completely.

There is a difference in opinion as to what constitutes a "wolf tree." Many trees which were so categorized and cut for that reason likely would have been left by someone else. An average of 52 percent of the cut trees were dominants and codominants, including 44 of the original 100 largest Douglas-fir trees per acre. Thus, whereas, on the average, thinnings at Voight Creek removed trees having poorer-than-average growth percents (after initial thinning, at least), many of the most rapidly growing trees were cut. Initial thinnings had a greater impact on growth per unit growing stock than did subsequent thinnings, probably because of the removal of these more vigorous trees.

Volumes removed at the initial thinnings were all reasonable. Current guidelines call for removing up to 33 percent of the volume in a single cut.[11] Subsequent thinnings were probably made

[11] Unpublished stocking-level guides prepared for Region 6, U.S. Forest Service, by David Bruce and Donald Reukema, 1972.

a little too frequently and removed too much of the volume accrued since the previous thinnings. Therefore, growing stock was reduced to too low a level at the more recent thinnings and was allowed to increase less than generally considered desirable.

Contrary to what some land managers expect, thinning only slightly changed relative tree size distribution in favor of larger trees. The benefit of increased rate of diameter growth was largely offset by removal of larger trees. These thinnings perhaps reduced the number of sawtimber size trees more than an average amount. However, if the better dominants and codominants are to receive adequate release, then other dominants and codominants must be cut; thus the number of such trees in the residual stand is reduced. Likewise, there is no reason to cut intermediate trees so long as they are maintaining an adequate growth rate and are expected to survive until the next entry. Their removal affords little, if any, release to neighboring dominant and codominant trees.

When the study was established, it was thought that the 6-year cycle would be nearly optimum, that the 9-year cycle would reduce growth due to removal of too much volume at a single thinning, and that the 3-year cycle would remove too little volume at a single cut to be economically feasible. However, it was found that, within the range applied, thinning interval had little effect on either growth or cost of thinning. Growth over the total 21-year period was reduced about equally on all thinning cycles. With highly mobile equipment, amount of volume removed had little effect on thinning cost.

SUMMARY AND CONCLUSIONS

Stands in which commercial thinnings were made at varying intervals, beginning at age 38, have now been observed for 21 years. Four treatments were compared: light thinning at 3-year intervals; moderate thinning at 6-year intervals; heavy thinning at 9-year intervals; and no thinning. All thinning treatments were designed to remove about the same volume over an 18-year period. Site index on the 210-acre experimental forest on which data were collected averages about 145 and ranges from about 100 to 170. The stand, which became established in about 1912, shows typical variation in stocking, density, and species composition.

Initial thinnings removed averages of 12, 22, and 31 percent of pretreatment volume. Subsequent thinnings plus mortality removed an average of 90 percent of the increment accrued since the previous thinning. Eighteen years after initial thinnings, standing volume was nearly equal to pretreatment volume and was about 64 percent of what it would have been if the stands had not been thinned. Size of cut trees was generally greatest at initial thinnings, where they were larger than average; those cut at subsequent thinnings were smaller than average. Over half of the cut trees were in the dominant and codominant crown classes and included an average of 44 of the original 100 largest Douglas-fir trees per acre.

Mortality volume was generally much less in thinned than in unthinned stands. Suppression mortality was much greater in unthinned stands, where it accounted for half of the total mortality

volume, whereas logging damage caused 15 percent of the mortality in thinned stands. Amount of mortality was greater in thinned stands during the period immediately following initial thinnings and greater in unthinned stands subsequently. Many surviving trees were damaged, but the effect of this damage on growth of the tree was erratic.

Eighteen years after initial thinnings, thinning had caused only a slight change in relative d. b. h. distribution in favor of larger trees. Thinned stands now contain fewer sawtimber size trees than unthinned stands and still contain smaller merchantable trees. Thinning apparently caused only a slight improvement in d. b. h. growth rate of the largest trees and had little effect on their height growth.

Thinning reduced gross cubic volume growth. On the average, relative 18-year growth was 20 percent less in thinned stands than in unthinned stands. In all periods, gross growth in thinned stands has been less than that in unthinned stands, the greatest reduction in growth taking place immediately following thinnings. Immediate reduction in growth rate associated with the 1955 freeze was greater in thinned than in unthinned stands; however, rate of recovery was also greater in thinned stands. Indications are that growth per acre in thinned stands will slowly approach that in unthinned stands, but it currently averages about 15 percent less.

Growth percent in thinned stands relative to unthinned stands has increased over time and is currently about 25 percent greater in thinned stands. The increase in growth percent achieved by thinning is due to a combination of (1) improved growth of residual trees and (2) removal of less efficient trees. Both factors had a substantial impact.

Usable cubic-foot yields to date (i. e., residual volume plus thinnings and salvable mortality) are less than 2 percent greater in thinned than in unthinned stands. A prediction indicates that total usable production to age 80 might be about 5 percent greater in thinned than in unthinned stands.

LITERATURE CITED

Bradley, R. T., J. M. Christie, and D. R. Johnston
1966. Forest management tables. For. Comm. Bookl. No. 16, 218 p. London.

Curtis, Robert O.
1966. A formula for the Douglas-fir total cubic-foot volume table from Bulletin 201. USDA Forest Serv. Res. Note PNW-41, 8 p. Pac. Northwest Forest & Range Exp. Stn., Portland, Oreg.

Duffield, John W.
1956. Damage to western Washington forests from November 1955 cold wave. USDA Forest Serv. Pac. Northwest Forest & Range Exp. Stn. Res. Note 129, 8 p., illus. Portland, Oreg.

Ford-Robertson, F. C. (ed.)
1971. Terminology of forest science, technology, practice and products. Multilingual For. Terminol. Ser. No. 1, 349 p., illus. Washington, D.C.: Soc. Am. For.

Harmon, Wendell H.
1969. Timber stand improvement thinning guidelines for Douglas-fir. J. For. 67(1): 36-39, illus.

McArdle, Richard E., Walter H. Meyer, and Donald Bruce
1961. The yield of Douglas fir in the Pacific Northwest. U.S. Dep. Agric. Tech. Bull. 201, 74 p., illus.

Reukema, Donald L.
1964a. Some effects of freeze injury on development of Douglas-fir. Northwest Sci. 38(1): 14-17, illus.

____
1964b. Crown expansion and stem radial growth of Douglas-fir as influenced by release. Forest Sci. 10(2): 192-199, illus.

Staebler, George R.
1955. Gross yield and mortality tables for fully stocked stands of Douglas-fir. USDA Forest Serv. Pac. Northwest Forest & Range Exp. Stn. Res. Pap. 14, 20 p., illus. Portland, Oreg.

____
1960. Theoretical derivation of numerical thinning schedules for Douglas-fir. Forest Sci. 6(2): 98-109, illus.

Tarrant, Robert F.
1950. A relation between topography and Douglas-fir site quality. J. For. 48(10): 723-724.

Turnbull, K. J., and G. E. Hoyer
1965. Construction and analysis of comprehensive tree-volume tarif tables. Resour. Manage. Rep. No. 8, 64 p., illus. Wash. State Dep. Natur. Resour., Olympia.

Worthington, Norman P., Donald L. Reukema, and George R. Staebler
1962. Some effects of thinning on increment in Douglas-fir in western Washington. J. For. 60(2): 115-119, illus.

__________ and George R. Staebler
1961. Commercial thinning of Douglas-fir in the Pacific Northwest. U.S. Dep. Agric. Tech. Bull. 1230, 124 p., illus.

GPO 986-548

Reukema, Donald L.
1972. Twenty-one year development of Douglas-fir stands repeatedly thinned at varying intervals. USDA Forest Serv. Res. Pap. PNW-141, 23 p., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Over an 18-year period, beginning at age 38, light thinnings at 3-year intervals, moderate thinnings at 6-year intervals, and heavy thinnings at 9-year intervals all reduced gross cubic volume growth by about 20 percent. This loss of growth was largely offset by salvage of mortality.

Keywords: Thinning (trees), Douglas-fir, growth, yield.

Reukema, Donald L.
1972. Twenty-one year development of Douglas-fir stands repeatedly thinned at varying intervals. USDA Forest Serv. Res. Pap. PNW-141, 23 p., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Over an 18-year period, beginning at age 38, light thinnings at 3-year intervals, moderate thinnings at 6-year intervals, and heavy thinnings at 9-year intervals all reduced gross cubic volume growth by about 20 percent. This loss of growth was largely offset by salvage of mortality.

Keywords: Thinning (trees), Douglas-fir, growth, yield.

Reukema, Donald L.
1972. Twenty-one year development of Douglas-fir stands repeatedly thinned at varying intervals. USDA Forest Serv. Res. Pap. PNW-141, 23 p., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Over an 18-year period, beginning at age 38, light thinnings at 3-year intervals, moderate thinnings at 6-year intervals, and heavy thinnings at 9-year intervals all reduced gross cubic volume growth by about 20 percent. This loss of growth was largely offset by salvage of mortality.

Keywords: Thinning (trees), Douglas-fir, growth, yield.

Reukema, Donald L.
1972. Twenty-one year development of Douglas-fir stands repeatedly thinned at varying intervals. USDA Forest Serv. Res. Pap. PNW-141, 23 p., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Over an 18-year period, beginning at age 38, light thinnings at 3-year intervals, moderate thinnings at 6-year intervals, and heavy thinnings at 9-year intervals all reduced gross cubic volume growth by about 20 percent. This loss of growth was largely offset by salvage of mortality.

Keywords: Thinning (trees), Douglas-fir, growth, yield.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.